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**Ohbayashi**

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(54) **RADIATION IMAGE CONVERTING PANEL,  
SCINTILLATOR PANEL AND RADIATION  
IMAGE SENSOR**

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(51) **Int. Cl.**  
**G01N 21/64** (2006.01)

(52) **U.S. Cl.** ..... **250/488.1**

(58) **Field of Classification Search** ..... 250/483.1,  
250/484.2-484.5, 361 R  
See application file for complete search history.

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*Primary Examiner*—David P Porta

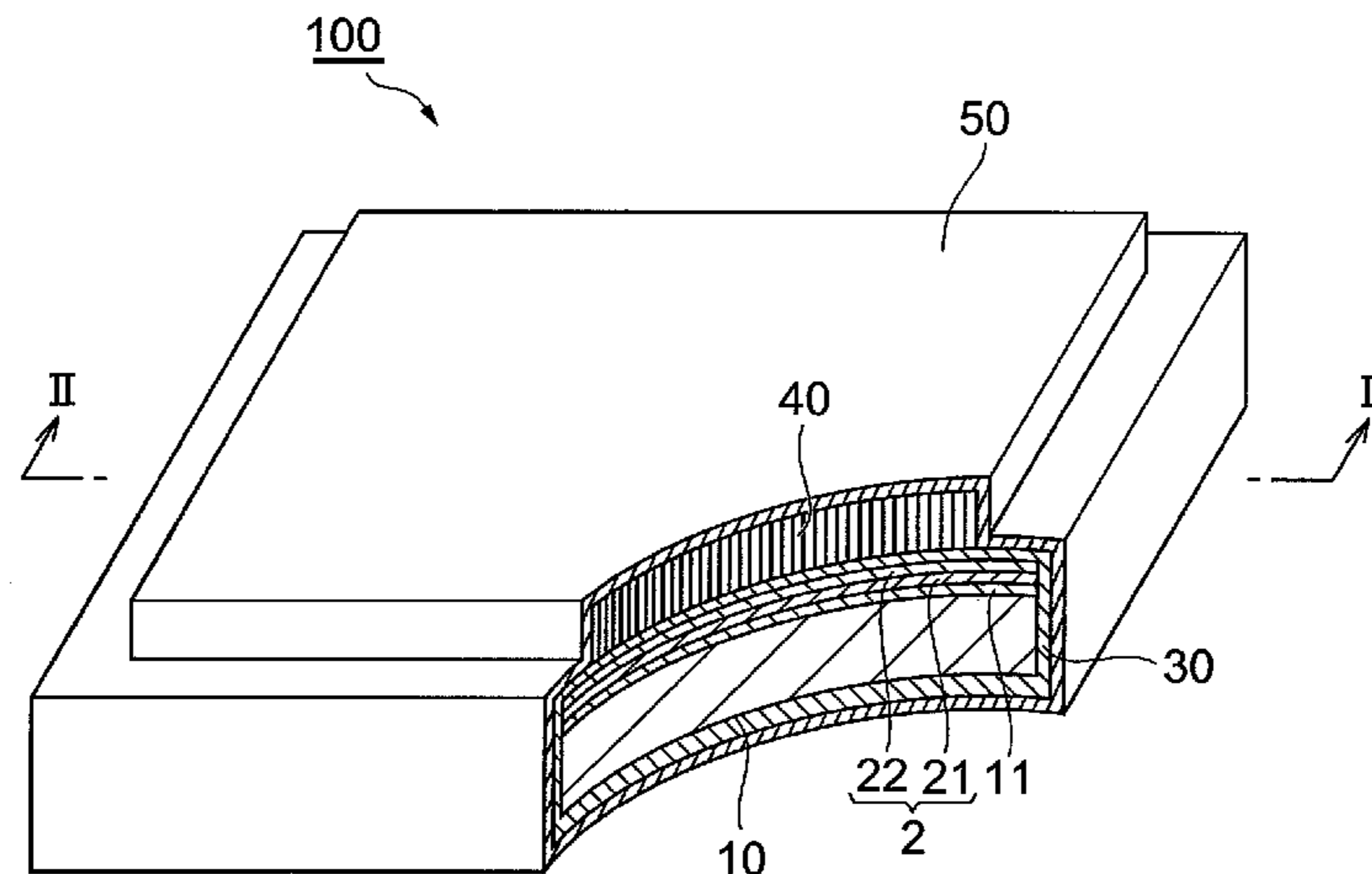
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(57) **ABSTRACT**

For a radiation image converting panel according to the present invention, a converting portion that converts a radiation image to an optical image is formed on a support for which a dielectric multilayer film is formed on a metal reflector, and the dielectric multilayer film includes at least a first dielectric layer that is in contact with the metal reflector and a second dielectric layer that is formed on the first dielectric layer and has a higher refractive index than that of the first dielectric film layer to light emitted by the converting portion.

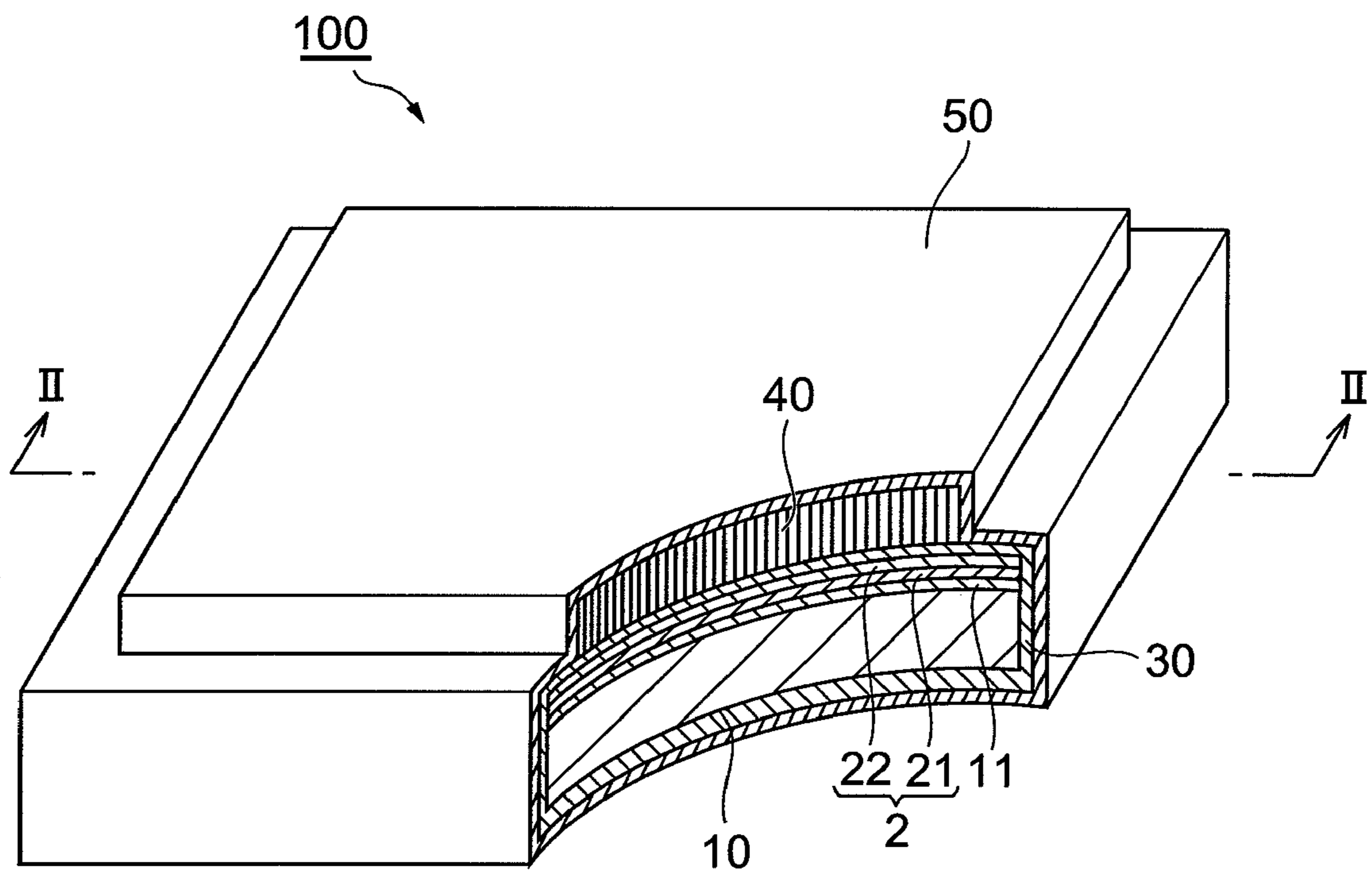
**12 Claims, 19 Drawing Sheets**



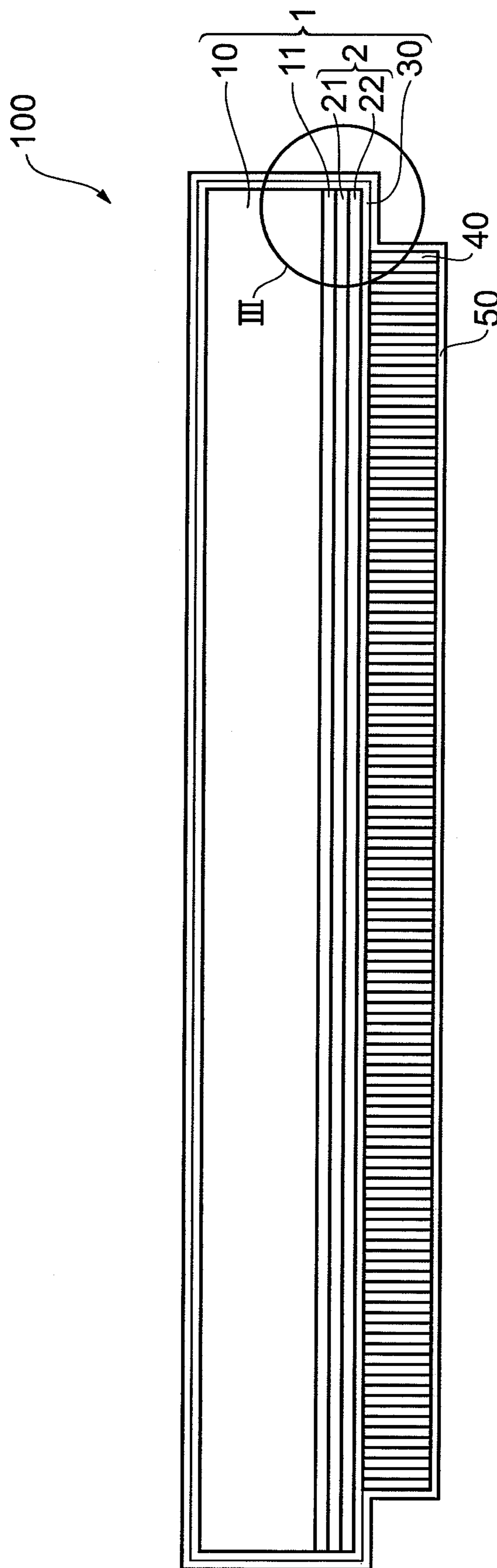
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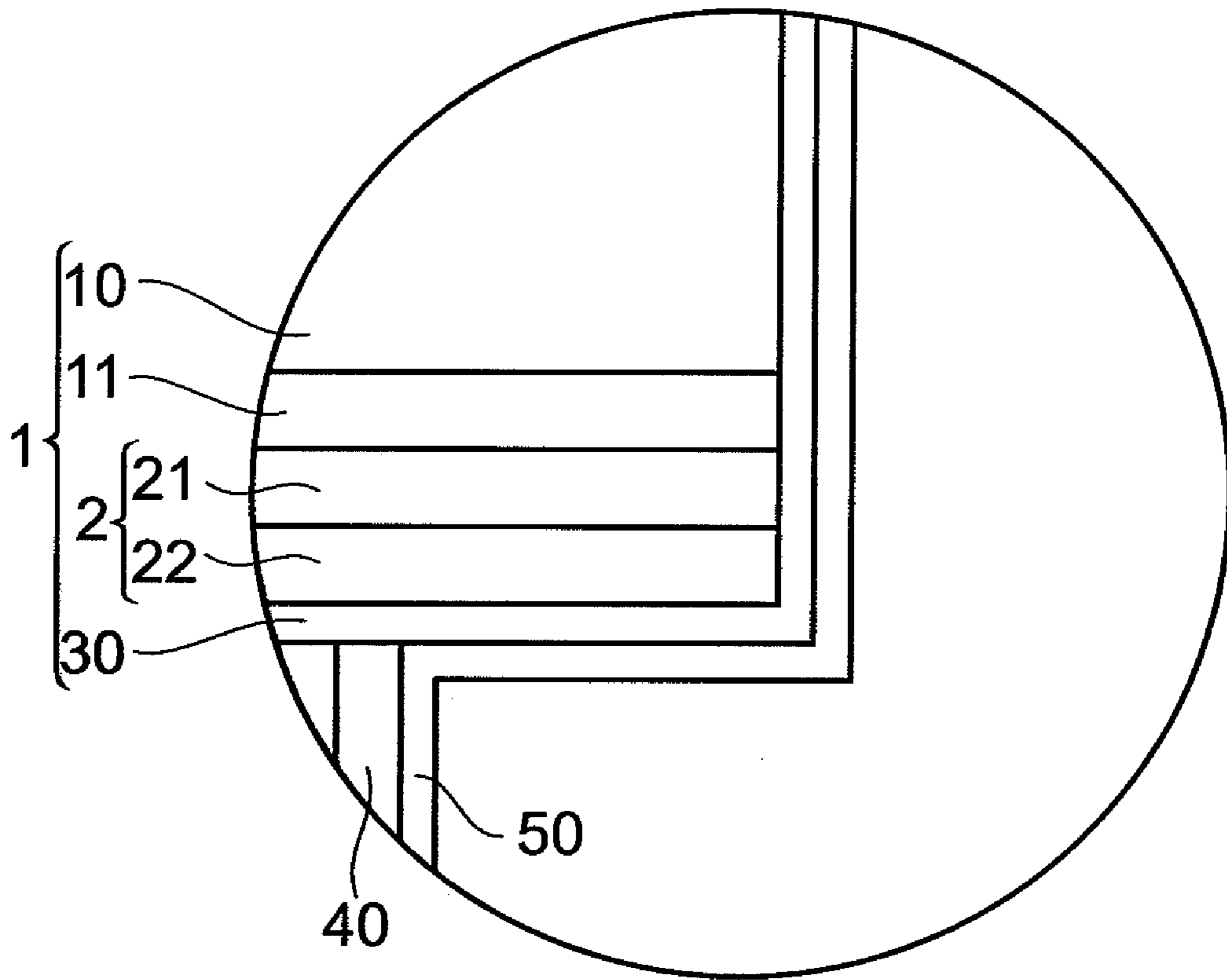
**Fig.1**



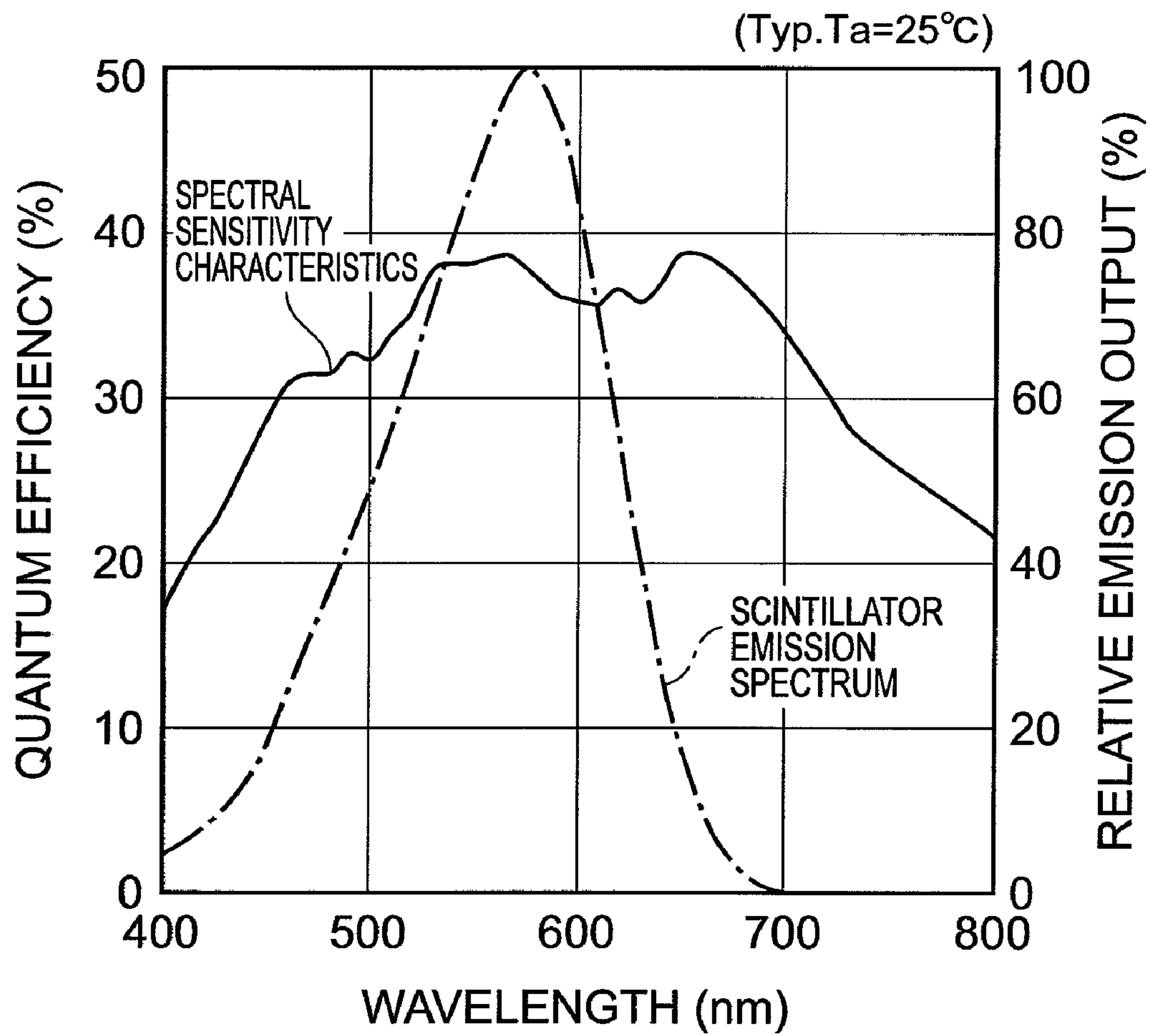
**Fig. 2**



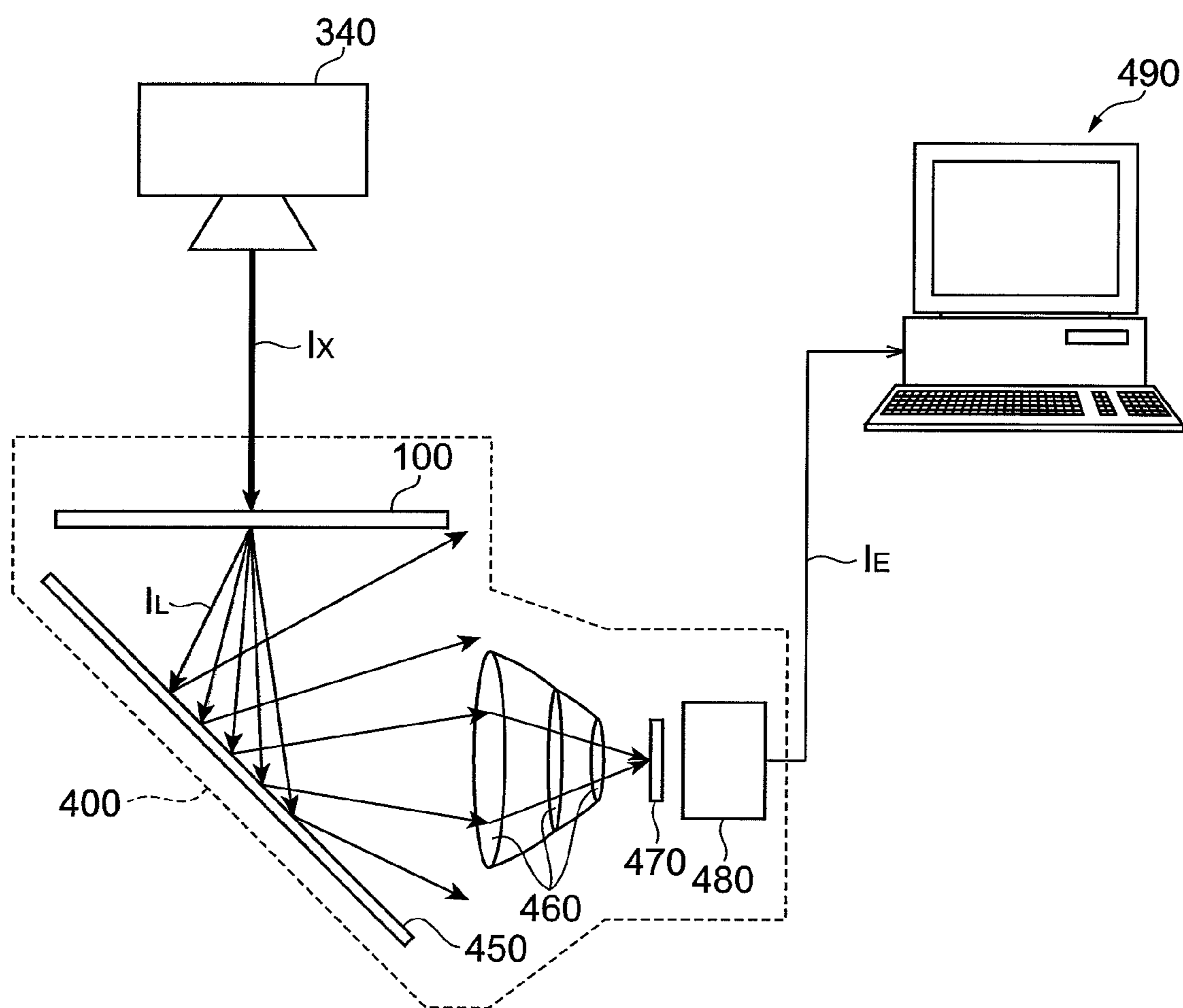
**Fig.3**



**Fig.4**

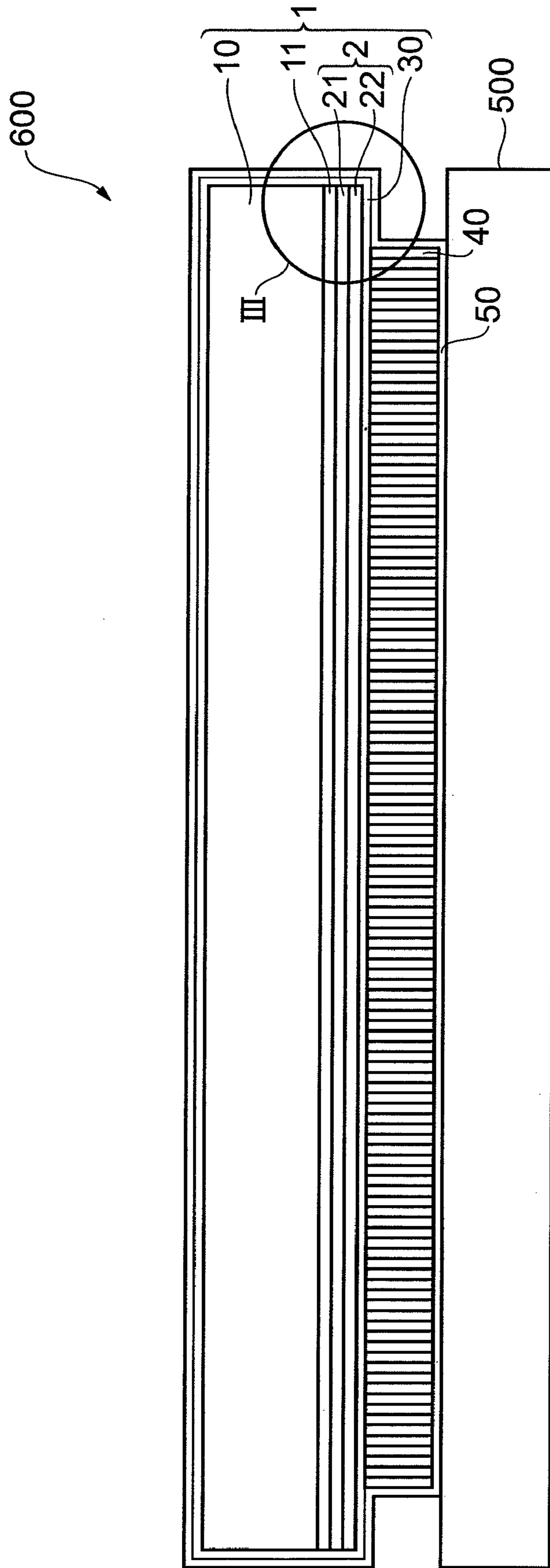


**Fig.5**



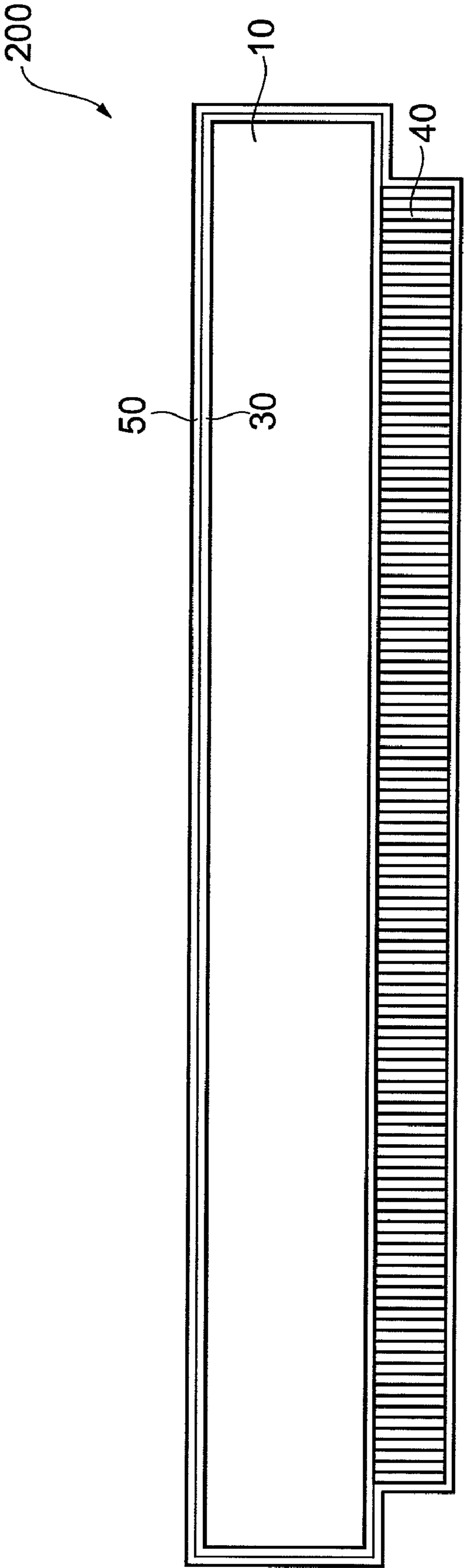


**Fig. 6**

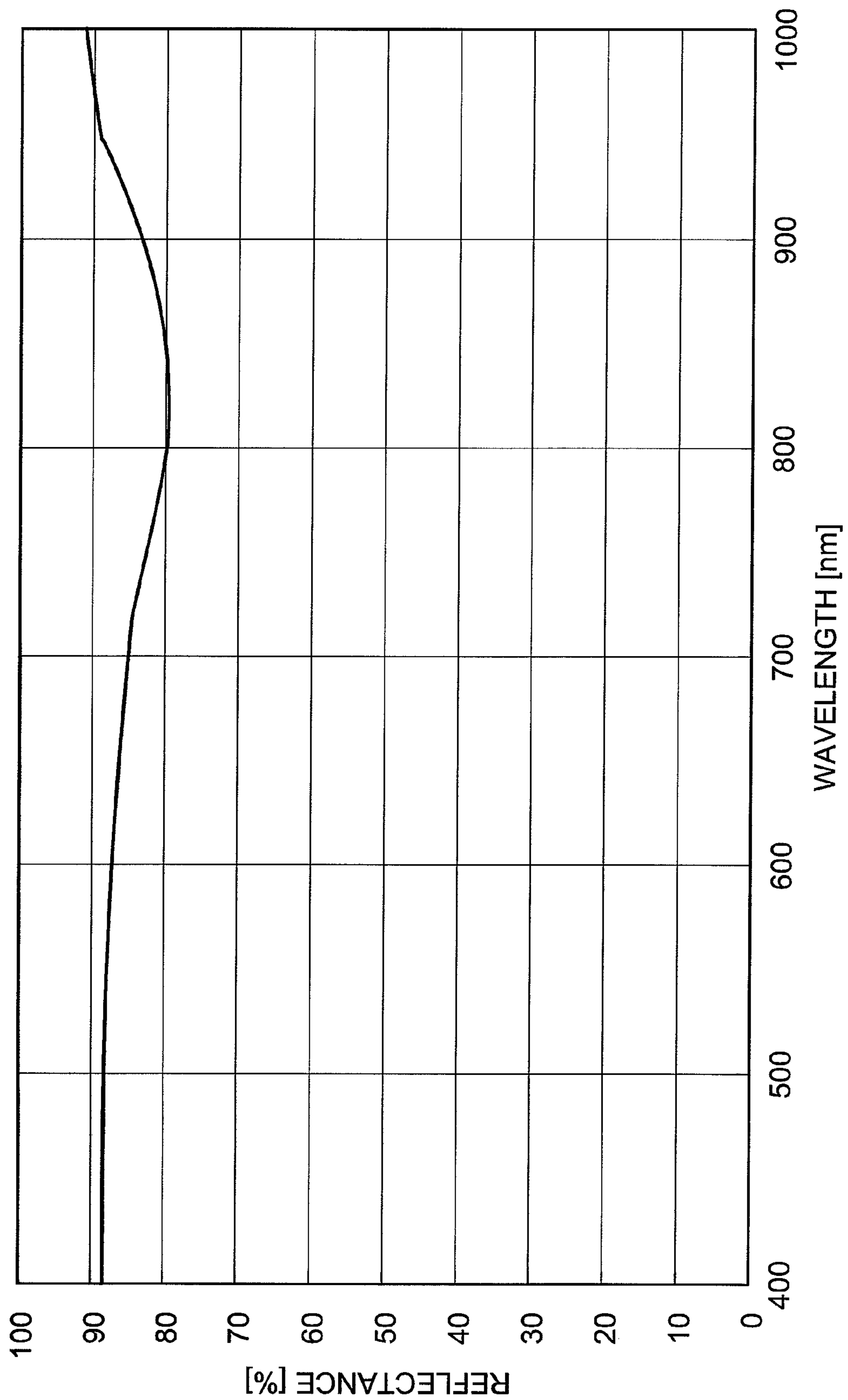




**Fig. 7**

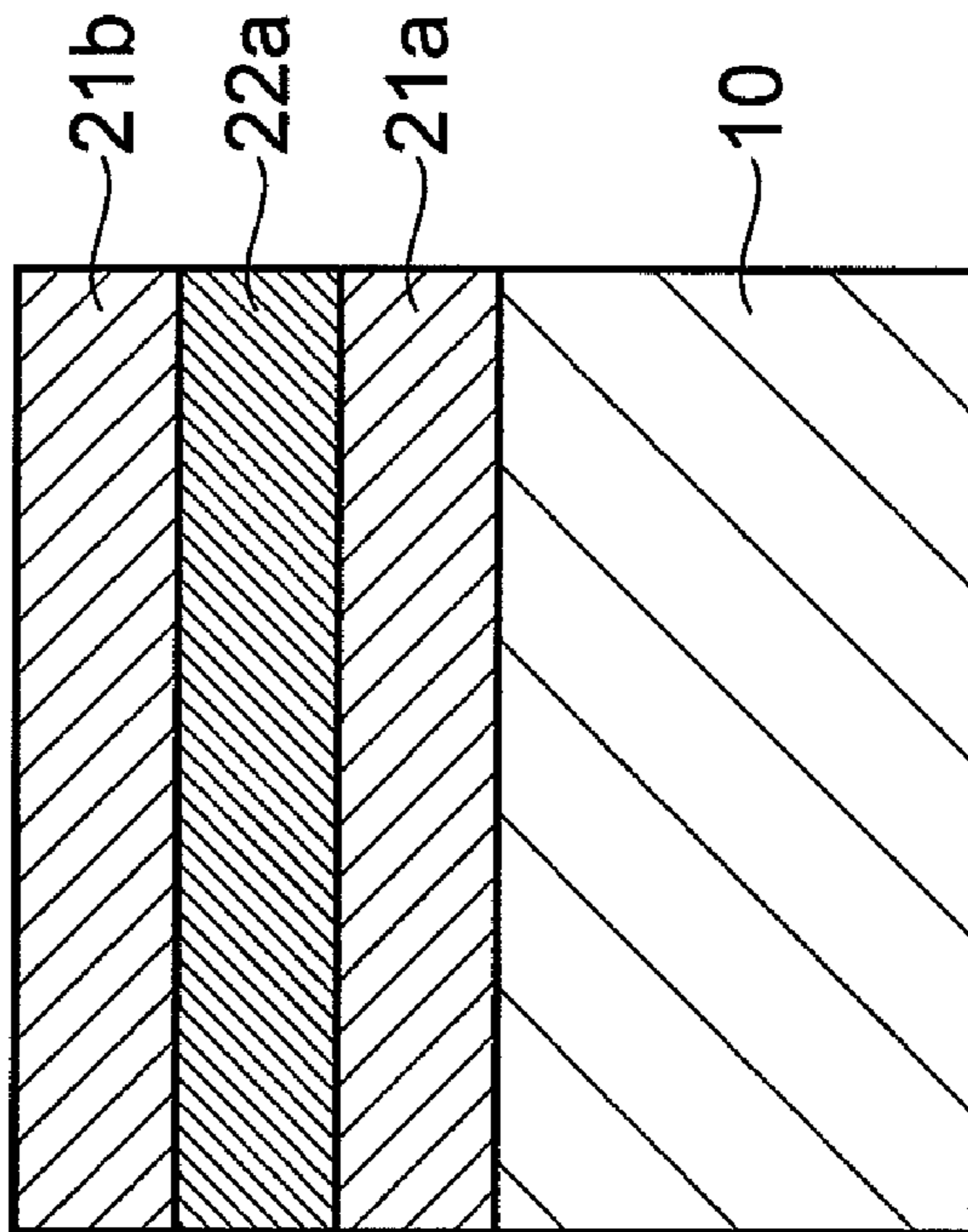


**Fig. 8**



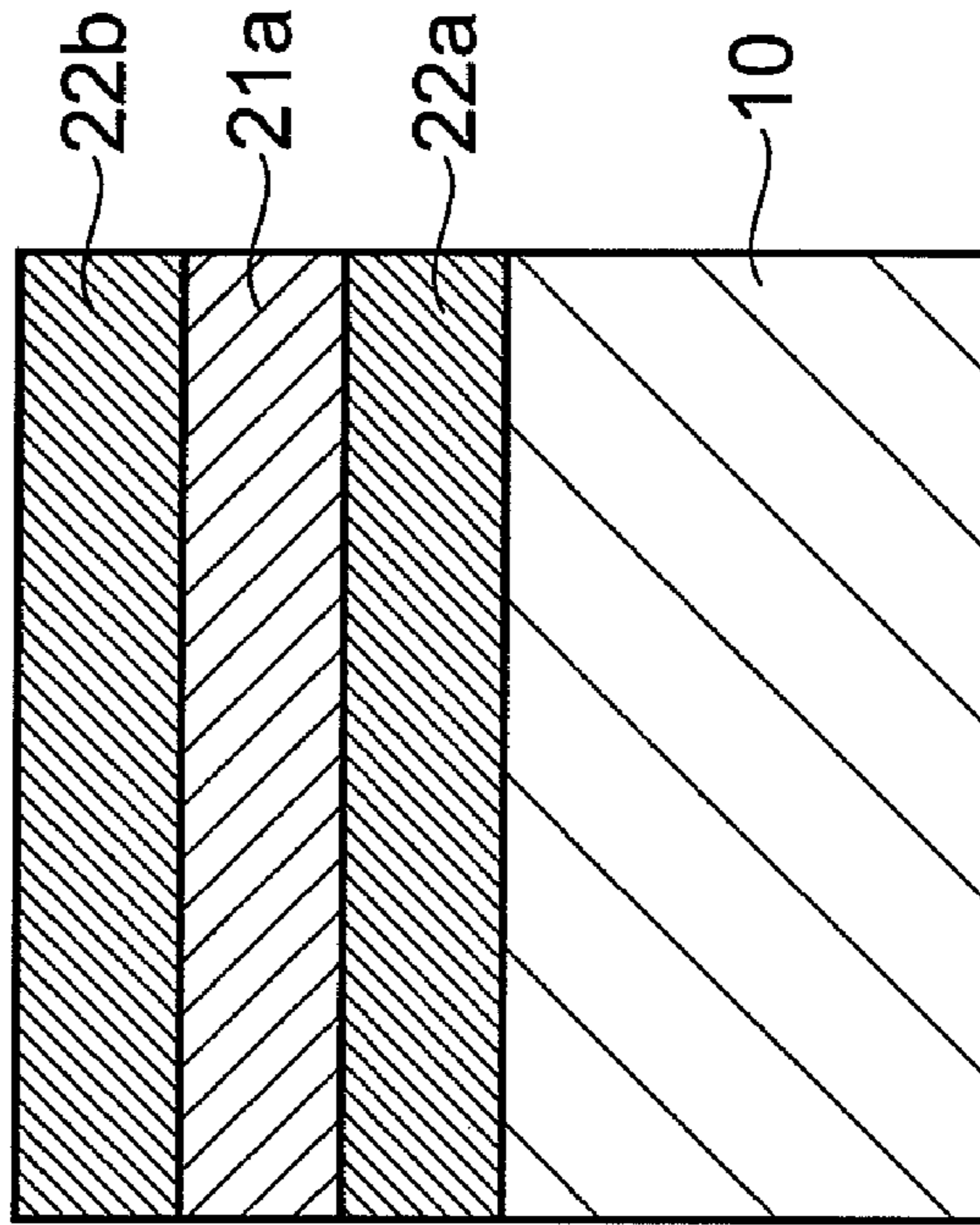
**Fig. 9A**

⋮

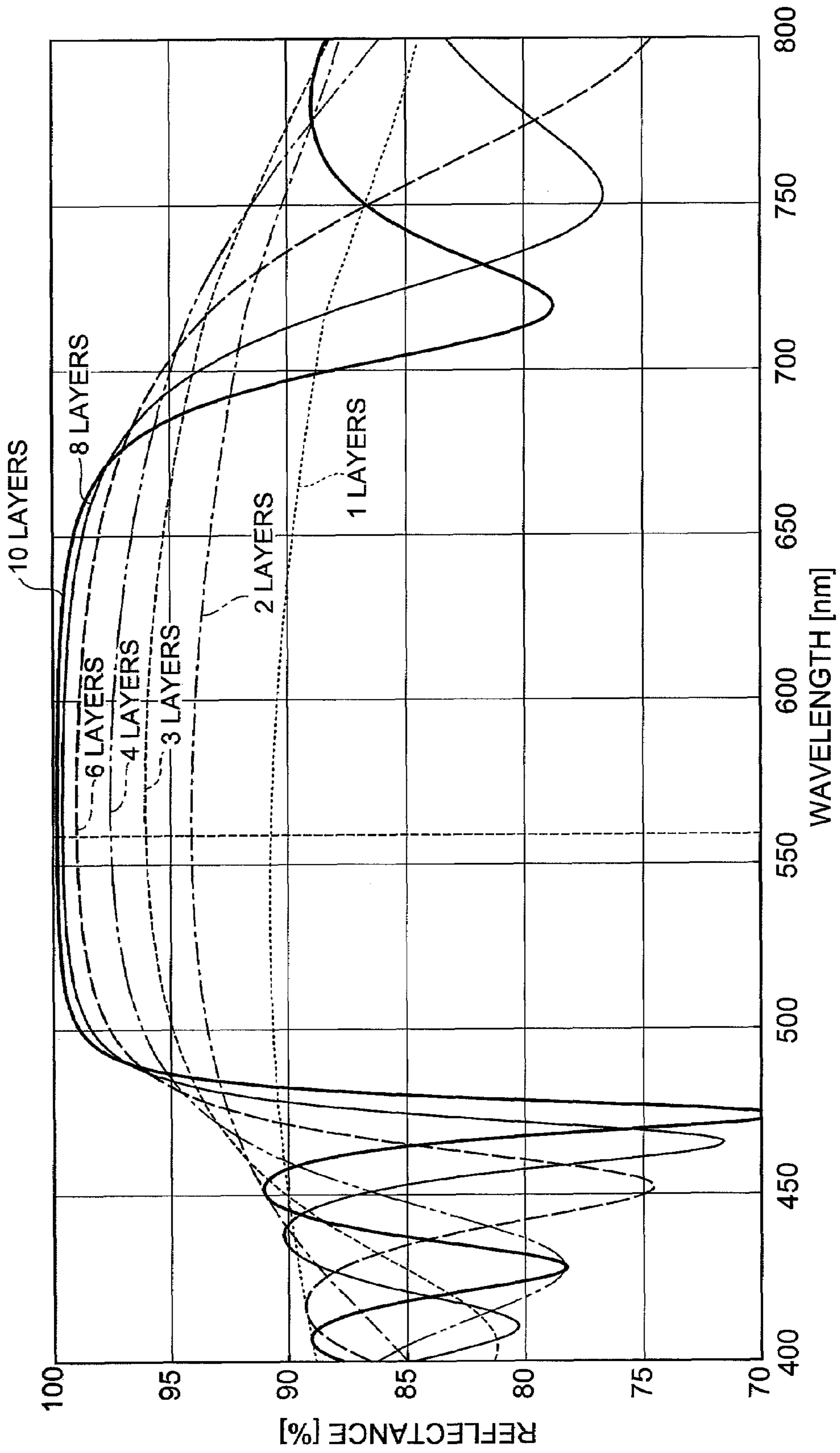


**Fig. 9B**

⋮



**Fig. 10**



**Fig. 11**

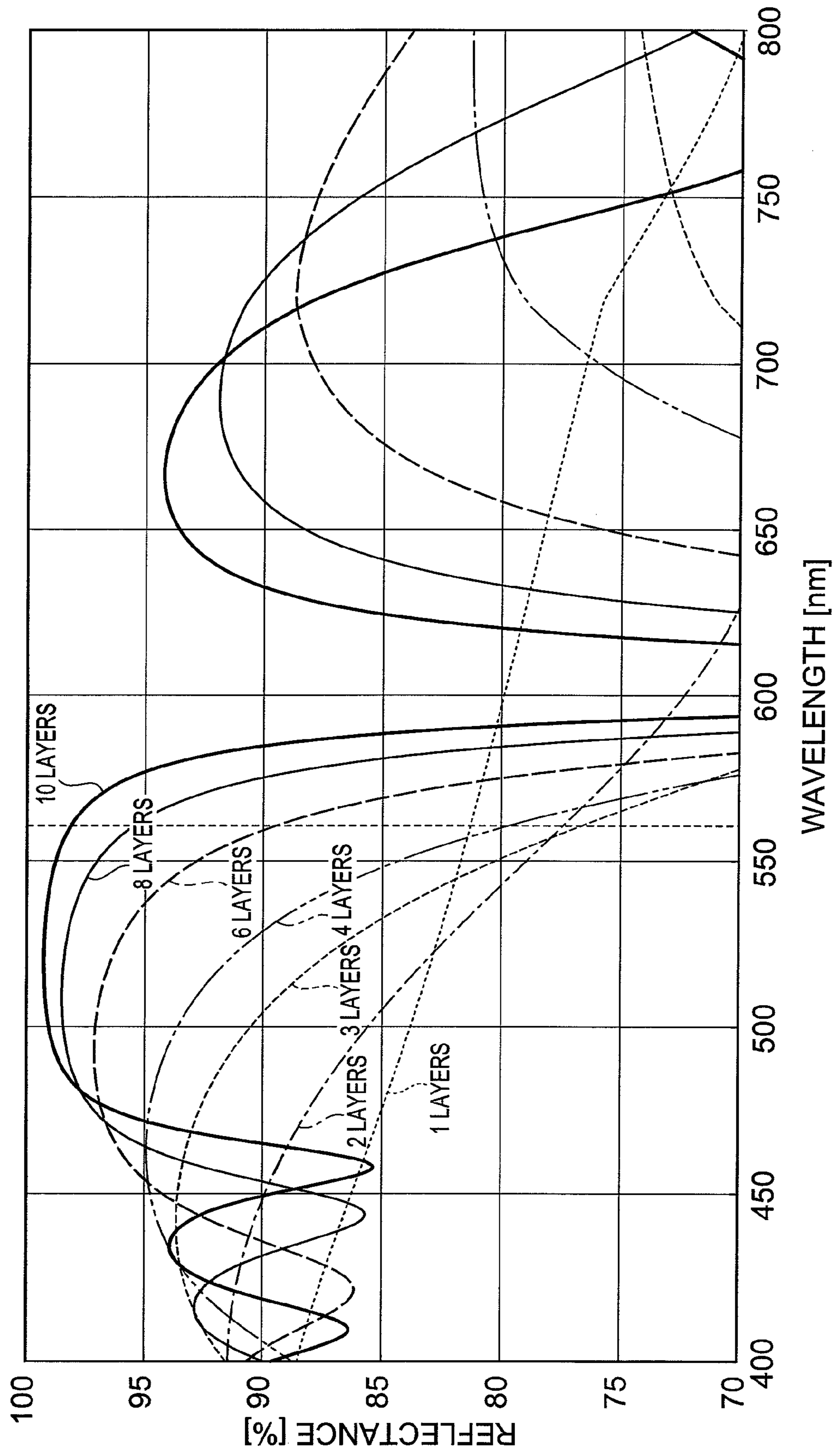
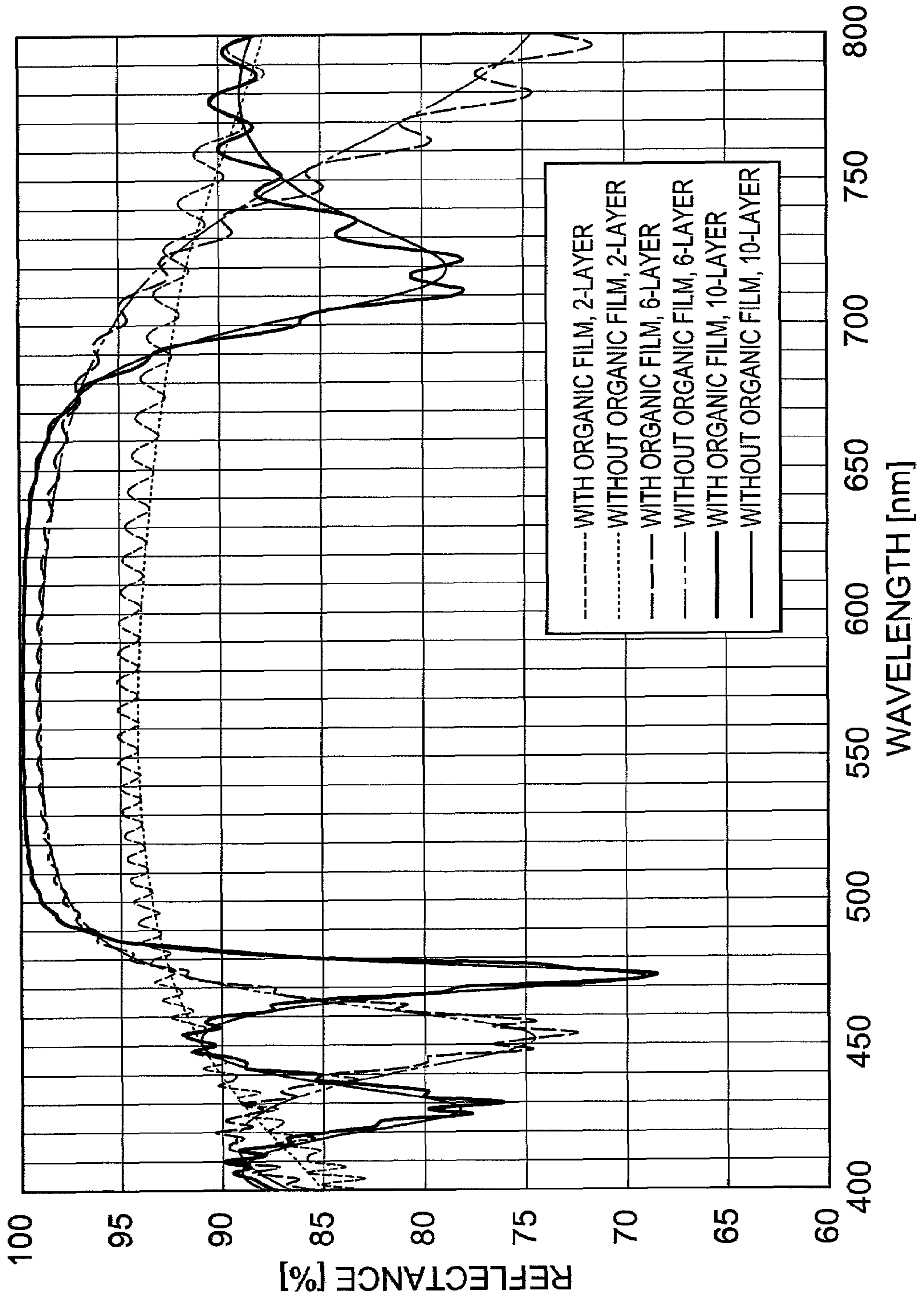
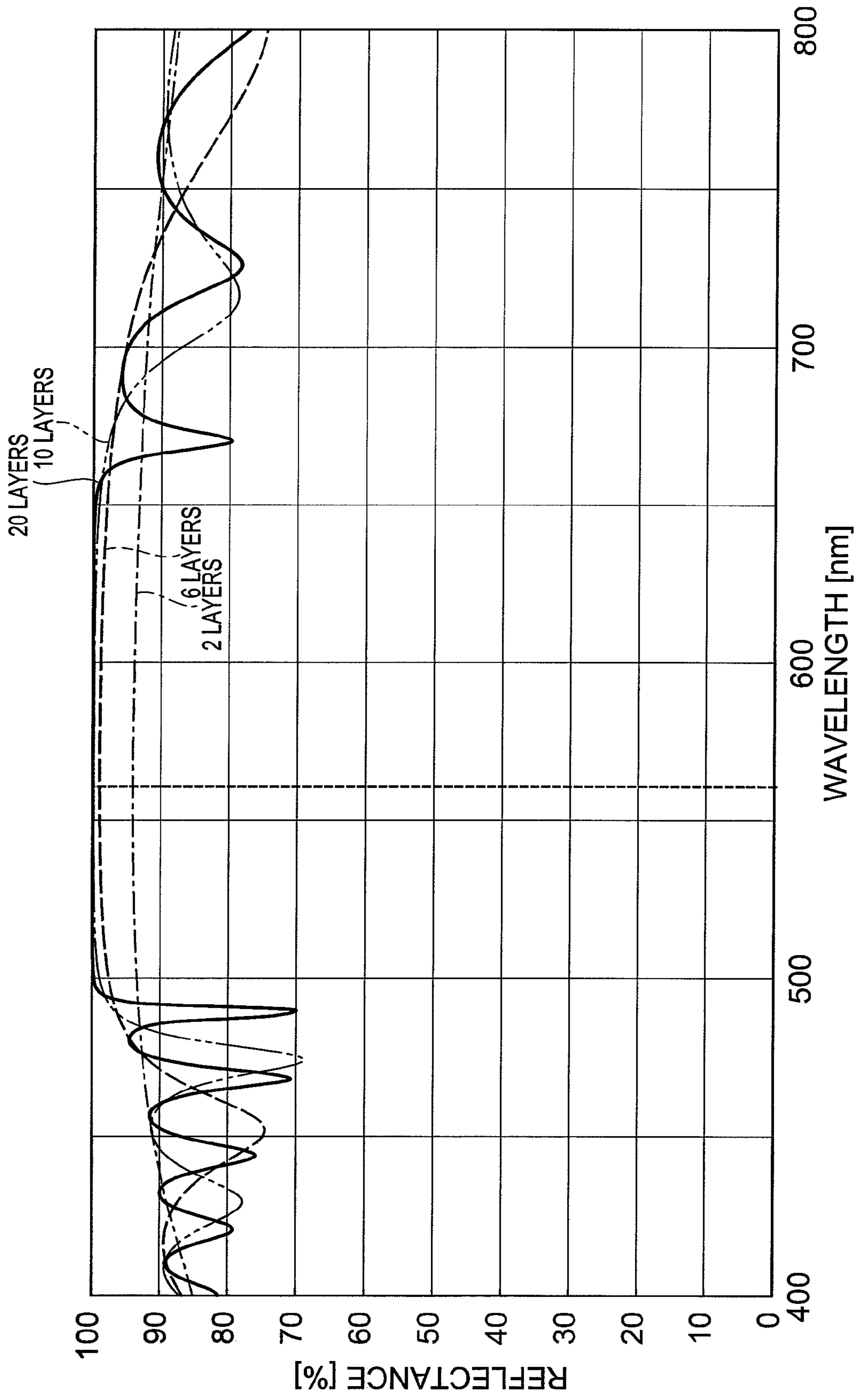




Fig. 12

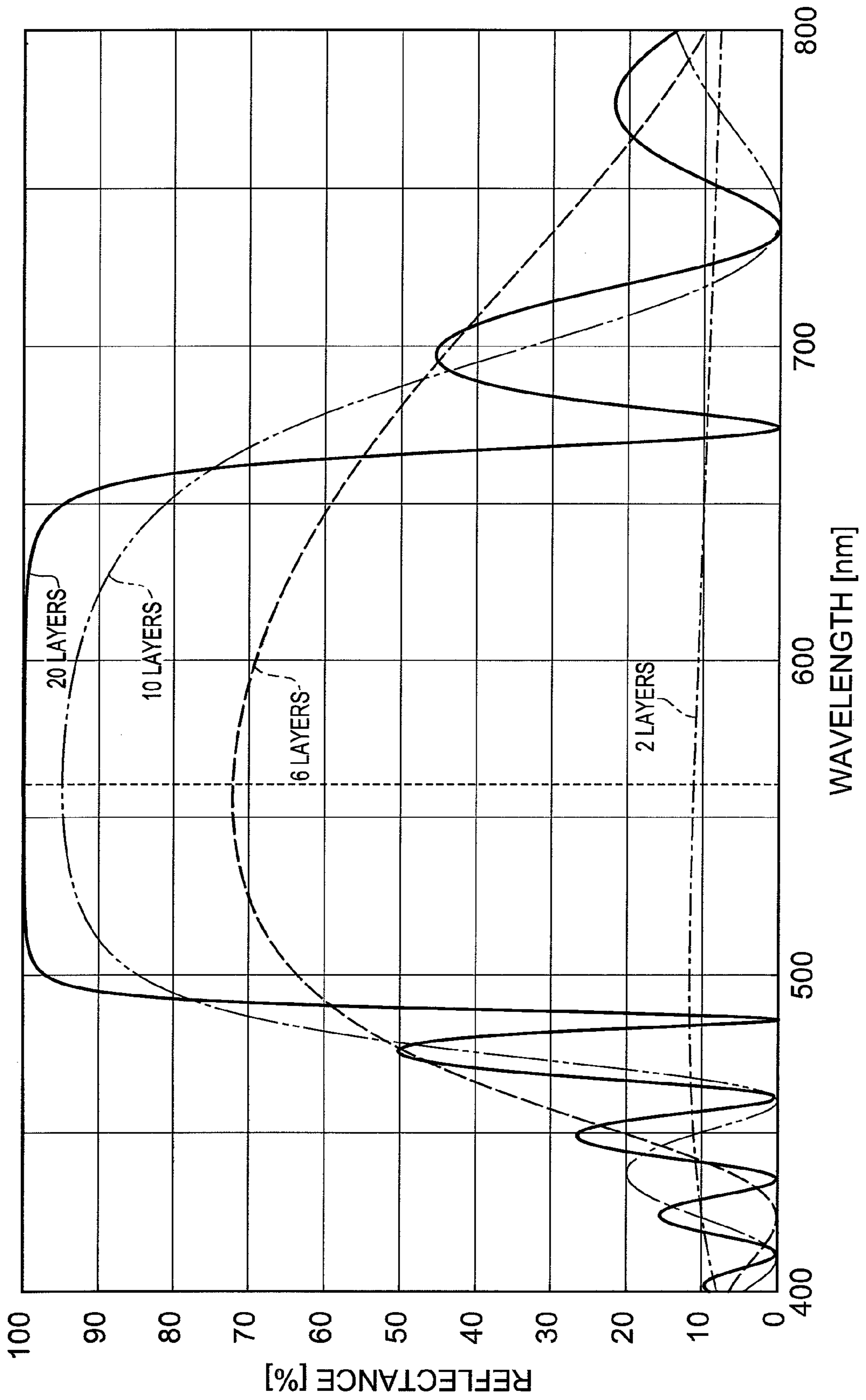


**Fig. 13**

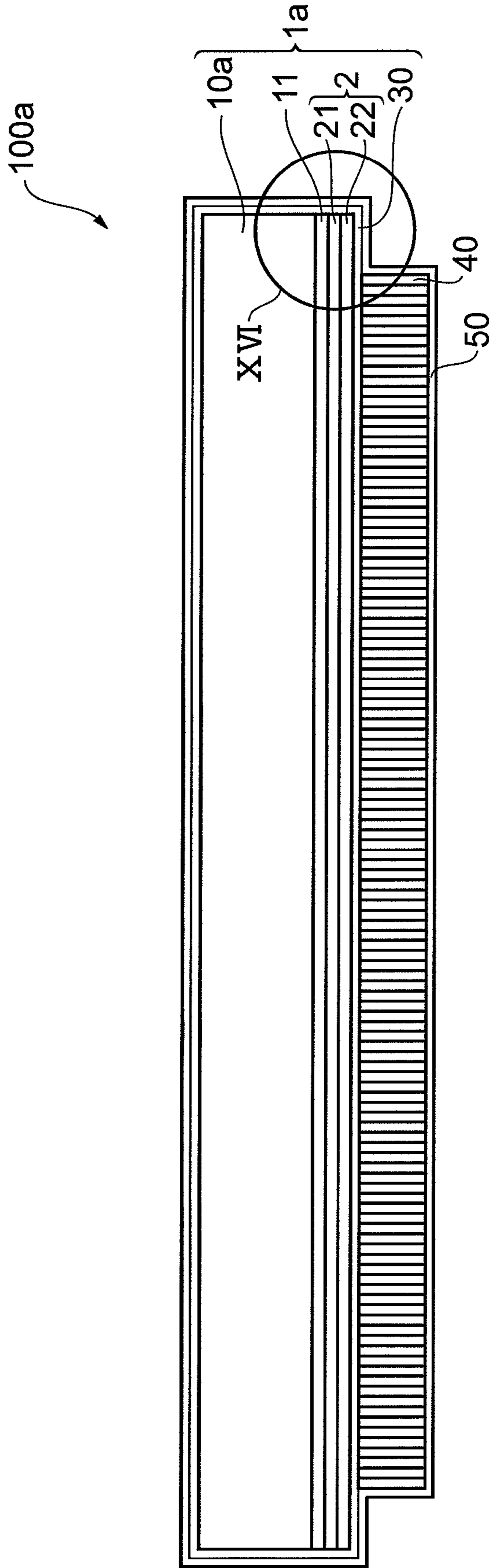




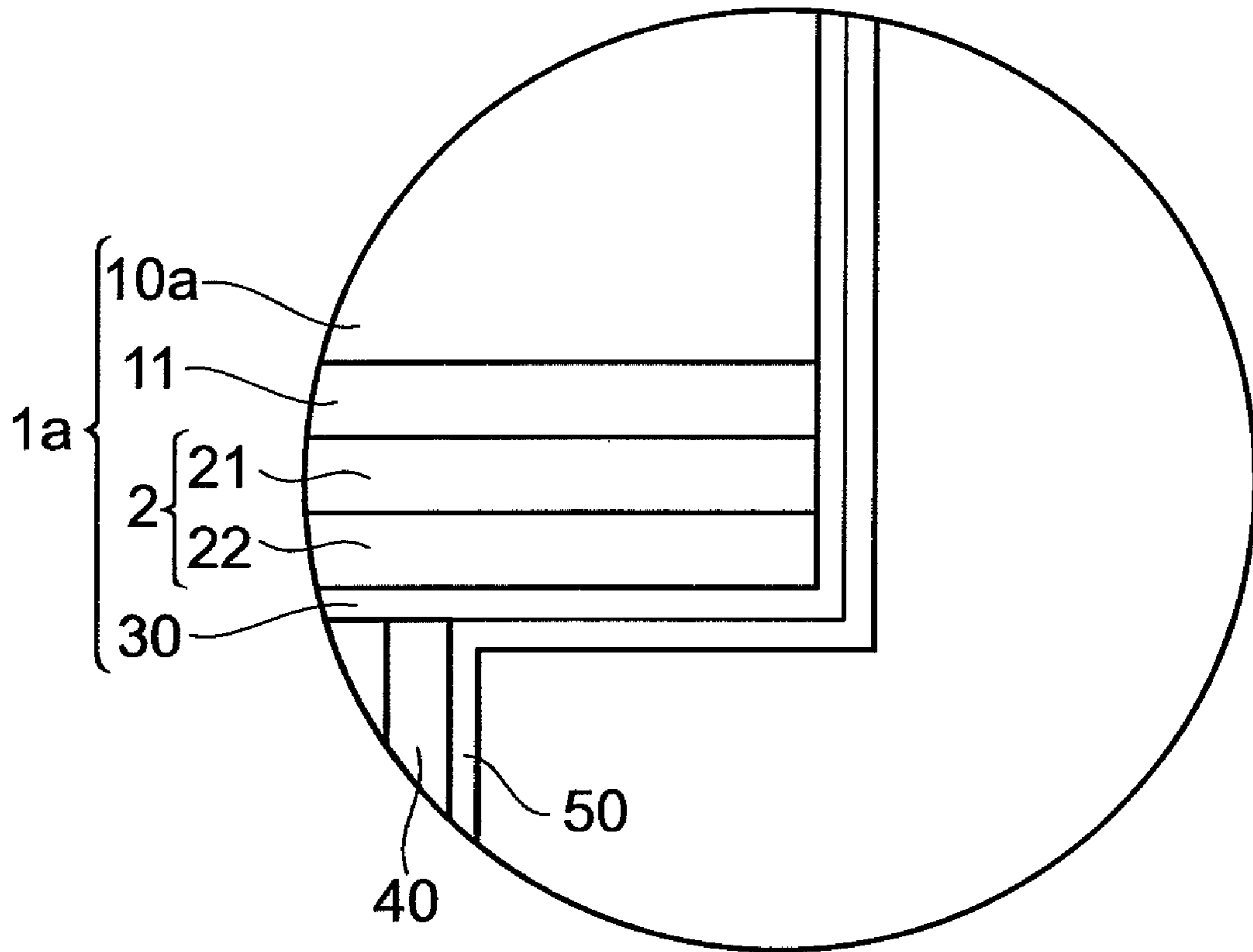
**Fig. 14**



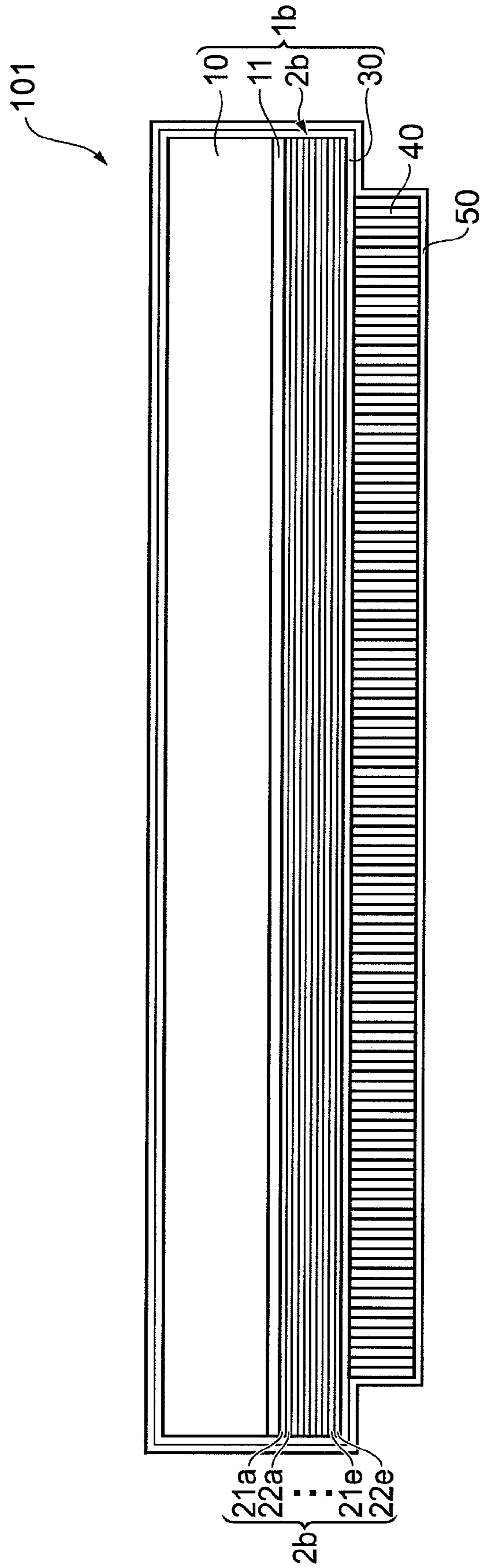
**Fig. 15**



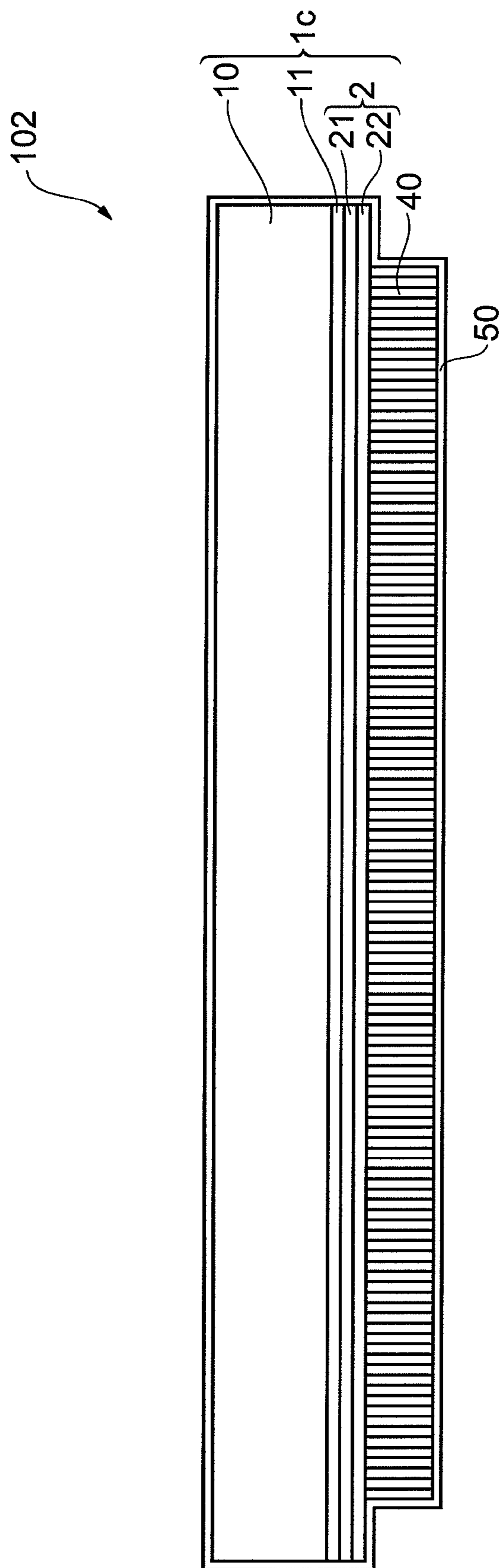
**Fig. 16**



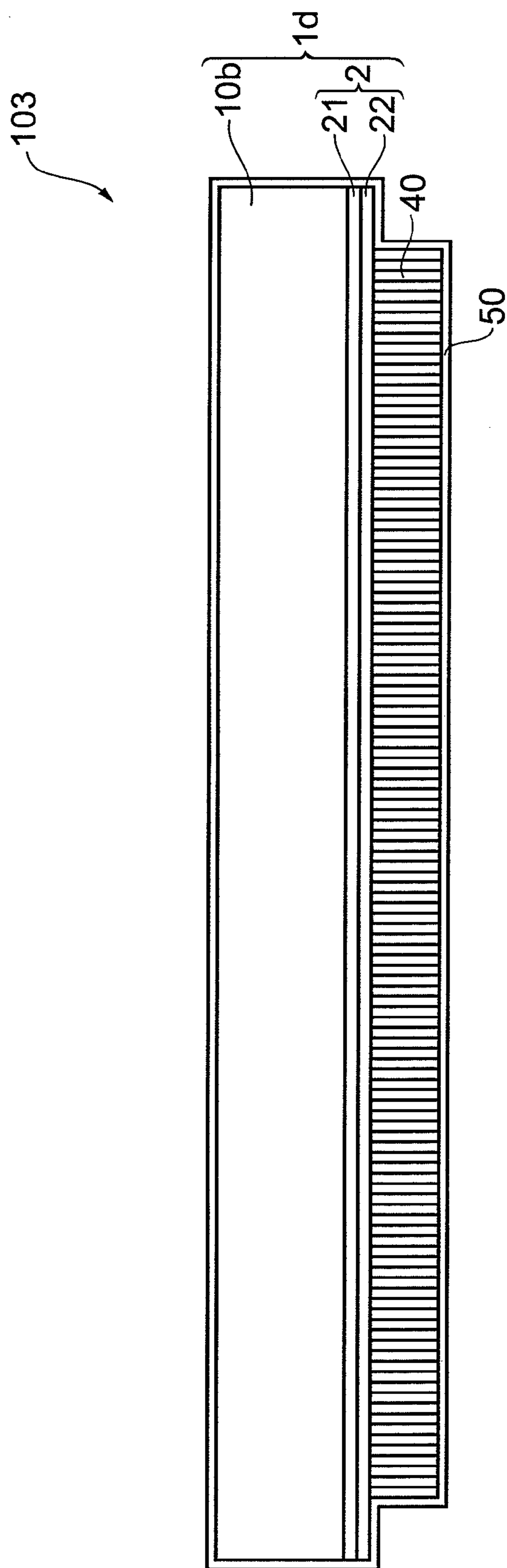
**Fig. 17**



**Fig. 18**



**Fig. 19**





# RADIATION IMAGE CONVERTING PANEL, SCINTILLATOR PANEL AND RADIATION IMAGE SENSOR

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention relates to a scintillator panel that converts a radiation image used for medical or industrial radiography or the like to an optical image.

### 2. Related Background Art

Conventionally, X-ray sensitive films have been used for medical or industrial radiography, however, radiation imaging systems using radiation detectors have become widespread from the aspects of convenience and storage stability of radiographic results. In such a radiation imaging system, two-dimensional image data by radiation is obtained as an electrical signal by the radiation detector, and this signal is processed by a processor and displayed on a monitor.

As a typical radiation detector, a radiation detector exists, having a structure for which a radiation image converting panel (hereinafter, referred to as a "scintillator panel") with a scintillator to convert radiation to a visible light formed on a substrate made of aluminum, glass, fused silica or the like is formed, and this is combined with an image pickup device. In this radiation detector, the scintillator converts radiation that is made incident to an optical image (not always of a visible light) in a wavelength range detectable by the image pickup device, and the image pickup device detects the optical image.

As scintillator panels structured as such, scintillator panels disclosed in International Publications WO 00/63722, WO 02/23219 A1, WO 02/23220 A1, etc., have been known. The scintillator panel disclosed in WO 00/63722 is one for which, on a radiation-transmissive substrate, a thin reflective metal film and a protective film are laminated, and a scintillator is deposited. The scintillator panel disclosed in WO 02/23219 A1 is one for which provided on a heat-resisting radiation-transmissive substrate is a dielectric multilayer film, and thereon a scintillator is deposited. The scintillator panel disclosed in WO 02/23220 A1 is one for which provided on a light-transmissive substrate is a dielectric multilayer film, and thereon a scintillator is deposited, and provided on either one or both of an interface between the dielectric multilayer film and light-transmissive substrate and a surface of the light-transmissive substrate opposite to the dielectric multilayer film is a light incidence/reflection inhibiting member that inhibits incidence/reflection of an unnecessary light. In these scintillator panels, radiation that has been transmitted through the substrate is made incident into the scintillator, converted to an optical image, and outputted from a surface thereof opposite to the incident surface of radiation, and a reflecting material provided between the scintillator and substrate reflects light emitted from the scintillator toward the substrate, whereby a radiation image with a high intensity can be obtained.

## SUMMARY OF THE INVENTION

In the scintillator panels described above, the higher the reflectance of the reflector, the higher the intensity of a radiation image can be obtained. In the case of a dielectric multilayer film, a high reflectance can be realized by increasing the number of layers thereof.

In recent years, scintillator panels have been increased in size in application to chest radiography and the like, however, it is difficult in terms of mass production to laminate multiple

layers of dielectric films with a uniform film thickness on such large-sized panels, and this causes an increase in the manufacturing cost. In addition, for obtaining a radiation image with a high intensity while inhibiting the amount of radiation exposure, it is desirable to reduce a loss due to absorption by the substrate etc., until radiation reaches the scintillator to the minimum, so that it is preferable to provide the substrate etc., as thin as possible. The more the substrate etc., is increased in size to become thinner, the more difficult it becomes to form multilayered dielectric films.

While the applicant has proceeded with development for mass production of a large-sized thin scintillator panel, the inventors have discovered in the course of development that a warp on the order of a few millimeters to a few tens of millimeters can occur to the substrate as a result of a scintillator formation when the substrate is thinned and increased in size. It was found that, when a warp occurred as such, an inorganic material that forms the dielectric film is low in resistance to deformation produced by this warp since this is poor in flexibility, elasticity, and ductility, and if the dielectric film layer is thickened, an inconvenience such that a crack is produced in the dielectric film occurs.

Furthermore, when an image sensor is adhered to the scintillator panel to form a radiation image sensor, it is necessary to flatten an adhering surface of the scintillator panel, and if such a warp as mentioned above has occurred in the scintillator panel, applying a stress to eliminate the warp results in a repeated stress application to the substrate, which makes a crack more likely to occur.

It is therefore an object of the present invention to provide a large-sized and thin radiation image converting panel, scintillator panel, and radiation image sensor which allow obtaining a radiation image with a high intensity and can be easily mass-produced.

In order to achieve the above object, for a radiation image converting panel according to the present invention, in a radiation image converting panel including a converting portion that converts a radiation image to an optical image on a support, the support includes: (1) a metal reflector; and (2) a dielectric film mirror including at least a first dielectric layer which is in contact with the metal reflector and formed thereon and a second dielectric layer which is formed on the first dielectric layer and has a higher refractive index than that of the first dielectric layer to light of an optical image outputted from the converting portion, and the converting portion is formed on the dielectric film mirror side.

In addition, for a scintillator panel according to the present invention, a scintillator is used as the converting portion of the above radiation image converting panel, and in a scintillator panel for which a scintillator composed of a plurality of needle crystals is formed on a support, the support includes: (1) a metal reflector; and (2) a dielectric film mirror including at least a first dielectric layer which is in contact with the metal reflector and formed thereon and a second dielectric layer which is formed on the first dielectric layer and has a higher refractive index than that of the first dielectric layer to light emitted from the scintillator, and the scintillator is formed on the dielectric film mirror side.

According to the inventor's knowledge, when combining a plurality of dielectric films different in the refractive index to compose a mirror, in the case of two layers, the refractive index as a whole becomes higher if a layer lower in the refractive index is provided as a first layer with reference to the side opposite to a light incident surface and thereon a layer higher in the refractive index than the first layer is laminated as the second layer. The present invention is based on this knowledge. By employing such construction as in the above,



a high light reflectance can be obtained even with a small number of layers, and not only can lamination be favorably performed even when the substrate is thin, but occurrence of a crack in the dielectric layers can also be prevented even when the substrate has been warped in a subsequent process, and thus a radiation image with a high intensity can be obtained, and mass production thereof also becomes easier.

It is preferable that the first dielectric layer contains  $\text{SiO}_2$ , and the second dielectric layer contains at least one material from  $\text{TiO}_2$ ,  $\text{Nb}_2\text{O}_5$ ,  $\text{Ta}_2\text{O}_5$ ,  $\text{HfO}_2$ , and  $\text{ZrO}_2$ . Since  $\text{SiO}_2$  is lower in the refractive index than any of  $\text{TiO}_2$ ,  $\text{Nb}_2\text{O}_5$ ,  $\text{Ta}_2\text{O}_5$ ,  $\text{HfO}_2$ , and  $\text{ZrO}_2$  and also has a large difference in the refractive index, a high reflectance can be realized.

More preferably, the dielectric film mirror is formed by laminating three or more layers of the first dielectric layer and the second dielectric layer alternately. By laminating three or more layers, the reflectance can be further improved.

However, when the number of laminations is increased, although the reflectance is improved, the difficulty in lamination is increased as described above, and resistance to a warp that can possibly be produced in a subsequent process is also lowered, and thus in consideration of simultaneous pursuit of a high reflectance and mass producibility, the number of laminations of the dielectric film mirror is 10 layers or less, or the film thickness thereof as a whole is 1  $\mu\text{m}$  or less.

The scintillator panel may further include a transparent organic film which is formed, on the dielectric film mirror, at least between the same and the scintillator, and has a lower refractive index than that of the second dielectric layer to light emitted by the scintillator. By such configuration, not only is the dielectric film mirror protected by the transparent organic film, but an effect to further improve the light reflectance can also be obtained.

As the metal reflector, a thin metal film or a metal substrate can be used, and when the metal reflector is a thin metal film, handling thereof becomes easy if the scintillator panel further includes a supporting substrate that supports the metal reflector. If these types of metal reflectors are formed of aluminum, silver, or gold, since the light reflectance of the reflectors themselves can be increased, the light reflectance as a whole is improved, which is preferable.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partially broken perspective view showing a configuration of a first embodiment of a scintillator panel according to the present invention,

FIG. 2 is a sectional view along a line II-II thereof, and

FIG. 3 is an enlarged view of a part III of FIG. 2;

FIG. 4 is a graph showing an emission spectrum of a typical scintillator CsI (T1) and a spectral sensitivity spectrum of a typical image sensor;

FIG. 5 is a schematic view showing a configuration of a radiation image sensor according to the present invention, and

FIG. 6 is a sectional view showing another configuration;

FIG. 7 is a sectional view showing a configuration of a scintillator panel to be a comparative example, and

FIG. 8 is a graph showing wavelength characteristics of light reflectance at an interface of the scintillator panel;

FIG. 9A is a view showing a lamination order of a dielectric layer in a scintillator panel according to the present invention, and FIG. 9B is a view showing a lamination order of a dielectric layer in the comparative example;

FIG. 10 is a graph showing wavelength characteristics of light reflectance of the dielectric layer shown in FIG. 9A, and FIG. 11 is a graph showing wavelength characteristics of light reflectance of the dielectric layer shown in FIG. 9B;

FIG. 12 is a graph showing wavelength characteristics of light reflectance in cases with and without an organic film provided on the surface of the dielectric layer shown in FIG. 9A;

FIG. 13 is a graph showing wavelength characteristics of light reflectance in cases where the substrate is made of aluminum in the scintillator panel having the configuration shown in FIG. 9A, and FIG. 14 is a graph showing wavelength characteristics of light reflectance in cases where the substrate is made of glass;

FIG. 15 is a sectional view showing a configuration of a second embodiment of a scintillator panel according to the present invention, and

FIG. 16 is an enlarged view of a part XVI thereof; and

FIG. 17 to FIG. 19 are sectional views showing respective configurations of third to fifth embodiments of a scintillator panel according to the present invention.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, preferred embodiments of the present invention will be described in detail with reference to the accompanying drawings. To facilitate the comprehension of the explanation, the same reference numerals denote the same parts, where possible, throughout the drawings, and a repeated explanation will be omitted. In addition, dimensions in the respective drawings have been overdrawn in part for the sake of description, and are not always coincident with those in reality.

FIG. 1 to FIG. 3 show a configuration of a first embodiment of a radiation image converting panel according to the present invention. The present embodiment is a scintillator panel using a scintillator as a converting portion of a radiation image and is therefore also a preferred embodiment of a scintillator panel according to the present invention. FIG. 1 is a partially broken perspective view thereof, FIG. 2 is a sectional view along a line II-II thereof, and FIG. 3 is an enlarged view of a part III of FIG. 2. This scintillator panel 100 is used for chest radiography and the like, and has a large size of, for example, 450 mm $\times$ 450 mm. As its configuration, a metal reflection film 11 made of aluminum, a  $\text{SiO}_2$  film 21, and a  $\text{TiO}_2$  film 22 are laminated on one of the surfaces of an aluminum substrate 10. And, all of these including the aluminum substrate 10 are covered by a reflection protective film 30 to form a support 1. A needle-shaped scintillator 40 is provided on the surface of the reflection protective film 30 on the  $\text{TiO}_2$  film 22 of the support 1, and further, the whole is covered by a moisture-resistant protective film 50.

The aluminum substrate 10 functions as a supporting substrate that supports the whole. When the thickness of the aluminum substrate 10 is less than 0.3 mm, the scintillator 40 tends to become easily peeled off due to curving of the aluminum substrate 10. On the other hand, when the thickness of the aluminum substrate 10 exceeds 1.0 mm, its radiation transmittance tends to decline. In order to secure intensity of radiation that is transmitted through this aluminum substrate 10 and made incident into the scintillator 40 while reliably forming the scintillator 40 on the substrate, it is preferable to provide the thickness of the aluminum substrate 10 as 0.3 mm or more and 11.0 mm or less.

As the metal reflection film 11, a thin film of gold, silver, aluminum, or the like can be used. The aluminum substrate 10 is usually formed by rolling, striped streaks are formed in the rolling process, and it is difficult to completely remove the streaks even by subsequent polishing. When the thickness of the metal reflection film 11 is less than 50 nm, unevenness



tends to occur on the reflection surface under the influence of the stripes. On the other hand, when the thickness thereof exceeds 200 nm, its radiation reflectance tends to decline. In consideration of balance between the light reflectance of the metal reflection film **11** and intensity of radiation made incident into the scintillator **40**, it is preferable to provide the thickness of the metal reflection film **11** as 50 nm or more and 200 nm or less. In the present embodiment, a thin aluminum film with a thickness of 70 nm is used, however, this may be analyzed as an incomplete aluminum oxide by an AES analysis (Auger Electron Spectroscopy).

Both of the SiO<sub>2</sub> film **21** and the TiO<sub>2</sub> film **22** compose a dielectric film mirror **2**. FIG. 4 is a graph showing an emission spectrum of the scintillator **40** of the present embodiment and spectral sensitivity characteristics of a MOS-type image sensor (C7921, manufactured by Hamamatsu Photonics K.K.), used in combination with the scintillator panel **100**, for obtaining an optical image. As shown in this graph, since the emission spectrum of the scintillator **40** has a central emission wavelength around 560 nm, it is necessary for the dielectric film mirror **2** to have a high reflectance in a range centered on this wavelength. As for the refractive index to light with a wavelength of 560 nm, SiO<sub>2</sub> is 1.46 and TiO<sub>2</sub> is 2.29, and thus the refractive index of the TiO<sub>2</sub> film **22** being the second layer is higher than the refractive index of the SiO<sub>2</sub> film being the first layer. Since it is sufficient to set the film thickness of both so that its optical film thickness becomes  $\lambda/4$  where a central wavelength of light to be reflected is provided as  $\lambda$ , it is sufficient to set the thickness of the SiO<sub>2</sub> film **21** to 95 nm and the thickness of the TiO<sub>2</sub> film to 60 nm. When a constituent of the scintillator **40** to be described later makes contact with the metal reflection film **11**, this can cause erosion of the metal reflection film **11**. The SiO<sub>2</sub> film **21** and TiO<sub>2</sub> film **22** existing between the metal reflection film **11** and scintillator **40** prevents contact of the constituent of the scintillator **40** with the metal reflection film **11**, and also has a function to prevent erosion and deterioration thereof.

The reflection protective film **30** has a function to further prevent erosion and deterioration of the metal reflection film **11** due to the constituent of the scintillator **40**. The SiO<sub>2</sub> film **21** and TiO<sub>2</sub> film **22** described above are formed by vapor deposition as will be described later, and fine pinholes may occur at that time. In such a case, if the scintillator **40** is formed directly on the TiO<sub>2</sub> film **22**, a constituent of the scintillator **40** reaches the metal reflection film **11** through the fine pinholes existing in the SiO<sub>2</sub> film **21** and TiO<sub>2</sub> film **22** to cause erosion and deterioration thereof. In the present embodiment, the reflection protective film **30** exists, so that even when pinholes have occurred at the time of a dielectric film formation, these openings can be effectively blocked to effectively inhibit the constituent of the scintillator **40** from reaching the metal reflection film **11**. In addition, this can also efficiently inhibit the constituent of the scintillator **40** from reaching the metal reflection film **11** from the lateral side of the aluminum substrate **10**.

On the other hand, since the scintillator **40** is generally formed of a deliquescent material, when the scintillator **40** is formed of such a deliquescent material, it is desirable to seal the scintillator **40** by the moisture-resistant protective film **50**.

As the reflection protective film **30** and moisture-resistant protective film **50**, an organic film or an inorganic film can be used, and different materials or the same material may be used. In the present embodiment, both films **30** and **50** are made from, for example, polyparaxylylene, but may be made from a xylylene-based material such as polymonochloroparaxylylene, polydichloroparaxylylene, polytetrachloroparaxylylene, polyfluoroparaxylylene, polydimethylparaxy-

lylene, or polydiethylparaxylylene. Alternatively, the reflection protective film **30** and moisture-resistant protective film **50** may be made from, for example, polyurea, polyimide, or the like, or may be made from an inorganic material such as LiF, MgF<sub>2</sub>, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, MgO, or SiN. Further alternatively, these may be formed in combination of an inorganic film and an organic film. In the present embodiment, the thickness of each protective film **30**, **50** is 10  $\mu$ m. The protective film **30** has a refractive index to light with a wavelength of 560 nm of 1.64, which is lower than the refractive index of the TiO<sub>2</sub> **22** being the second layer and higher than the refractive index of the SiO<sub>2</sub> film **21** being the first layer.

The scintillator **40** is smaller than the aluminum substrate **10** when viewed from the thickness direction of the aluminum substrate **10**. In other words, the scintillator **40** is formed not on the whole of a scintillator **40** forming surface of the aluminum substrate **10** but in a partial region on the surface. The region of the surface of the aluminum substrate **10** formed with the scintillator **40** may be surrounded by regions formed without the scintillator **40** on four sides, however, regions formed without the scintillator **40** may exist only at three or two sides thereof and the scintillator **40** may be formed up to the ends of the substrate **10** on the other sides.

The scintillator **40** is made of, for example, a phosphor that converts radiation to a visible light, and is composed of CsI columnar crystals or the like doped with Tl, Na, or the like. The scintillator **40** has a construction bristled with a plurality of needle crystals. The scintillator **40** may be made of NaI doped with Tl, KI doped with Tl, or LiI doped with Eu. Alternatively, the scintillator **40** may be of a type that emits infrared or ultraviolet light other than visible light. The thickness of the scintillator **40** is preferably 100  $\mu$ m to 1000  $\mu$ m, and more preferably, 450  $\mu$ m to 550  $\mu$ m. The average needle diameter of the needle crystals that compose the scintillator **40** is preferably 3  $\mu$ m to 10  $\mu$ m.

Next, description will be given of a manufacturing process of this scintillator panel **100**. First, the aluminum substrate **10** is prepared. Next, on this aluminum substrate **10**, the metal reflection film **11** is formed by a vacuum vapor deposition method. Subsequently, the SiO<sub>2</sub> film **21** and TiO<sub>2</sub> film **22** are laminated similarly by a vacuum vapor deposition method. Then, the reflection protective film **30** is formed by a CVD method so as to seal the aluminum substrate **10**, the metal reflection film **11**, and the dielectric film mirror **2** as a whole. Subsequently, by a vapor deposition method, the scintillator **40** is formed at a predetermined position on the reflection protective film **30**. Next, the moisture-resistant protective film **50** is formed by a CVD method so as to seal the whole of the aluminum substrate **10**, the metal reflection film **11**, and dielectric film mirror **2** sealed by the reflection protective film **30** and the scintillator **40** formed thereon altogether. In this manner, the scintillator panel **100** is manufactured. Here, sealing of the protective film **30**, **50** can be realized by making the opposite surface side of the aluminum substrate **10** to the scintillator forming surface float up from a substrate holder that supports the substrate in the apparatus at the time of CVD. Such methods include a method described in, for example, the specification of U.S. Pat. No. 6,777,690. According to this method, pins are used to float the aluminum substrate **10**. In this case, no protective film is formed on a minute contact surface between the aluminum substrate **10** and pins.

Next, we will describe actions and effects of this scintillator panel **100**. This scintillator panel **100** is used as a part of a radiation image sensor. FIG. 5 is a schematic configuration view showing one embodiment (first embodiment) of a radia-



tion image sensor (a radiation image sensor according to the present invention) using this scintillator panel.

This radiation image sensor **400** includes the scintillator panel **100** and an image pickup device **470** that converts an optical image  $I_L$  emitted from the scintillator **40** of the scintillator panel **100** to an electrical signal  $I_E$ . Between the image pickup device **470** and the scintillator panel **100**, arranged is a mirror **450** and a lens **460** as a reducing optical system that demagnifies an optical image  $I_L$  and guides the image to an imaging plane of the image pickup device **470**. The reducing optical system is not limited to the illustrated construction but may be composed only of either the mirror or lens, and the mirror and lens may be either a single or a plurality of mirrors and lenses. In addition, a prism and other optical components may be used besides the mirror and lens.

To describe the case of chest radiography for example, located as a subject is a reagent (not shown) between the surface (hereinafter, referred to as a "radiation input surface") of the scintillator panel **100** on the side where the scintillator **40** has not been formed and a radiation source **340**. Radiation emitted from the radiation source **340** toward the reagent partially passes through the reagent, and an obtained radiation image  $I_x$  is made incident into the radiation input surface of the scintillator panel **100**.

The radiation made incident into the scintillator panel **100** passes through the moisture-resistant protective film **50**, reflection protective film **30**, the aluminum substrate **10**, the metal reflection film **11**, the dielectric film mirror **2**, and the reflection protective film **30**, and is made incident into the scintillator **40**. The scintillator **40** emits visible light according to the radiation made incident. Thereby, a visible optical image  $I_L$  according to the radiation image  $I_x$  is generated.

A part of the visible light emitted from the scintillator **40** passes through the moisture-resistant protective film **50** and is outputted from the surface (hereinafter, referred to as a "optical image output surface") of the scintillator panel **100** on the side opposite to the radiation input surface. In addition, a part is outputted in the opposite direction, that is, to the dielectric film mirror **2** side, but is reflected by the reflection protective film **30**, the dielectric film mirror **2**, and the metal reflection film **11** to return to the scintillator **40** side, and is finally outputted from the optical image output surface after passing through the scintillator **40** and the moisture-resistant protective film **50**.

Since the scintillator panel **100** of the present embodiment employs the thin aluminum substrate **10**, this allows securing intensity of radiation made incident into the scintillator **40** to obtain a radiation image (in actuality, the optical image  $I_L$  corresponding to the radiation image  $I_x$ ) with a high intensity. In addition, since light emitted from the scintillator **40** is effectively guided by the reflection protective film **30**, the dielectric film mirror **2**, and the metal reflection film **11** to the optical image output surface to be outputted, intensity of the output optical image can be further increased. Since this allows obtaining an optical image corresponding to a radiation image with a sufficient intensity even when the intensity of light made incident is low, the amount of radiation made incident into the subject can be reduced, and an effect to lower the amount of radiation exposure of the subject can also be obtained.

The optical image  $I_L$  outputted from the scintillator panel **100** is demagnified by the mirror **450** and the lens **460** and is guided to the imaging plane of the image pickup device **470**. As the image pickup device **470**, besides, for example, a solid-state image pickup device such as a CCD (Charge-Coupled Device) or a CMOS (Complementary Metal Oxide Semiconductor) device, a pickup tube or the like can be used.

The image pickup device **470** outputs the electrical signal  $I_E$  according to the optical image  $I_L$  made incident from the imaging plane. The outputted electrical signal  $I_E$  is sent to an analyzing workstation **490** through an electronic device **480**, and is applied with a predetermined processing to display an image onto a display or accumulate/store image information onto a storage device such as hard disk. The electrical signal  $I_E$  corresponding to the image may be sent as an analog signal to the workstation **490** or may be converted to a digital signal by the electronic device **480** or the image pickup device **470** itself. The electronic device **480** may apply, without limitation to digitization, other processes to the obtained electrical signal  $I_E$ . In addition, the electronic device **480** may control operation of the image pickup device **470**. In the present embodiment, using the reducing optical system provides an advantage that a small-sized image pickup device can be used as the image pickup device **470**.

The radiation image sensor using the scintillator panel **100** of the present embodiment is not limited to the embodiment mentioned above. FIG. **6** is a sectional view showing a configuration of another radiation image sensor using the scintillator panel **100** of the present embodiment. A radiation image sensor **600** of this embodiment includes the scintillator panel **100** and an image pickup device **500** which is arranged in a manner opposed thereto and converts light outputted from the scintillator **40** of the scintillator panel **100** to an electrical signal. Here, the optical image output surface of the scintillator panel **100** is arranged on the imaging plane side of the image pickup device **500** side. That is, the scintillator **40** is arranged between the image pickup device **500** and the substrate **10**. The scintillator panel **100** and the image pickup device **500** may be joined or may not be joined to each other. In addition, it is not always necessary that these are in contact, and these may be arranged apart. When both are joined, these may be joined by an adhesive, or an optical coupling material (refractive index matching material) may be used to lower a light loss so that emitted light is efficiently guided to the imaging plane of the image pickup device **500** in consideration of the refractive indices of the scintillator **40** and the protective film **50**. In addition, both may be mechanically combined by use of an unillustrated fixing member.

Similar to the radiation image sensor of the first embodiment, in the present embodiment as well, a radiation image made incident from the radiation input surface is converted to an electrical signal by being made incident into the scintillator **40**, is converted to an optical image, and is guided to the image pickup device **500**. By guiding this electrical signal to an unillustrated analyzing device, a display, accumulation/storage, or the like can be performed, and the same effects as those of the radiation image sensor of the first embodiment can be obtained. In the present embodiment, since the scintillator panel **100** and the image pickup device **500** can be integrated, handling thereof becomes easy, and there is also an advantage that omitting an optical system makes an adjustment easy.

Next, we will describe verification results of the difference in effects depending on the existence of the dielectric film mirror **2** of the scintillator panel **100** of the present embodiment. FIG. **7** is a sectional view showing a configuration of a scintillator panel **200** to be a comparative example. This scintillator panel **200** has a configuration provided by sealing the aluminum substrate **10** by the protective film **30**, forming the scintillator **40** on one of the surfaces thereof, and covering the whole by the moisture-resistant protective film **50** while excluding the metal reflection film **11** and the dielectric film mirror **2** from the scintillator panel **100** according to the



present embodiment, and other aspects of the configuration are the same as those of the scintillator panel **100**.

FIG. **8** is a graph showing a spectral reflectance at the scintillator **40** forming surface of the substrate **10** and the protective film **30** viewed from the scintillator **40** side in the scintillator panel **200** of FIG. **7**. It can be understood that there is an absorption loss of slightly over 10% although the surface has a reflectance of 80% to 90% from the visible light region to the near-infrared light region.

Next, we will describe the case where the dielectric film mirror **2** is provided. FIG. **9A** and FIG. **9B** show dielectric mirror parts of scintillator panels, where both of these employ a construction of the SiO<sub>2</sub> film **21** and the TiO<sub>2</sub> film **22** alternately laminated on the aluminum substrate **10**, and these are different only in the lamination order thereof. In the dielectric mirror shown in FIG. **9A**, as in the scintillator panel **100** according to the present embodiment, a SiO<sub>2</sub> film **21a** with a low refractive index is provided as a first layer on the aluminum substrate **10** and a TiO<sub>2</sub> film **22a** with a high refractive index is thereon provided as a second layer, and this is then repeated. On the other hand, in the dielectric mirror shown in FIG. **9B**, contrary thereto, a TiO<sub>2</sub> film **22a** with a high refractive index is provided as a first layer on the aluminum substrate **10** and a SiO<sub>2</sub> film **21a** with a low refractive index is thereon provided as a second layer, and this is then repeated.

FIG. **10** and FIG. **11** show spectral reflectances in cases of the respective constructions of FIG. **9A** and FIG. **9B**. According to the construction of FIG. **9A**, a reflectance of nearly 95% can be obtained even when the dielectric mirror is composed of two layers as in the present embodiment, the reflectance exceeds 99% with six layers, and a reflectance of 99.8% is obtained with ten layers. According to the construction of FIG. **9B**, a phenomenon of a great depression of the reflectance is recognized around 600 nm. In the emission spectrum of the scintillator **40** (see FIG. **4**), the amount of energy in this region where the reflectance is depressed is not negligible, so that the intensity of an optical image to be obtained becomes lower than that of the construction of FIG. **9A**.

FIG. **12** is a graph showing by comparison spectral reflectances when, in the construction of FIG. **9A**, the protective film **30** is provided and not provided on the surface thereof. As shown in FIG. **12**, although the reflectance has a tendency to fluctuate finely and periodically when an organic film is formed in comparison with when no organic film is provided, it can be understood that the reflectance as a whole has been improved. Table 1 shows the difference in light reflectance at a wavelength of 560 nm to the number of laminations of dielectric layers in this construction.

TABLE 1

Light reflectance by number of layers	
Number of layers	Reflectance (%)
0	87.75
1	90.00
2	94.61
3	95.69
4	97.76
5	98.21
6	99.08
7	99.27
8	99.63
9	99.71
10	99.85

It can be understood from this table that an effect to improve reflectance when the TiO<sub>2</sub> film serving as an even

number layer was laminated is larger than the effect to improve reflectance when the SiO<sub>2</sub> film **21** serving as an odd number layer was laminated. Therefore, in consideration of cost performance etc., it is preferable to provide the number of laminations as an even number.

FIG. **13** and FIG. **14** are graphs showing by comparison spectral reflectances by the material of the substrate **10** in FIG. **9A**. FIG. **13**, which shows spectral reflectances in the case of the substrate **10** shown in FIG. **9A**, is a simplified graph of FIG. **10**. FIG. **14** shows spectral reflectances when the substrate **10** shown in FIG. **9** was replaced by a glass substrate. It can be understood that there is virtually no difference therebetween when the number of layers is large (20 layers), however, the spectral reflectance receives an influence of the substrate layer when the number of layers is small. Accordingly, it has been confirmed to be preferable that the first layer of the dielectric mirror is formed on a light reflection surface as shown in the present embodiment when the number of layers is small.

As has been described above, although it is preferable that the number of layers of the dielectric films is large for improving reflecting characteristics thereof, since a reflectance of nearly 95% can be obtained even with two layers and a reflectance of 99.85% can be obtained with ten layers, the effect to improve reflectance to be provided by further multilayered dielectric films is small. Meanwhile, the materials composing the dielectric films are poor in flexibility, elasticity, and ductility. During a manufacturing process of the scintillator panel **100** of the present embodiment, a warp on the order of a few millimeters to a few tens of millimeters can occur in the substrate **10** due to a formation of the scintillator **40**, however, the dielectric films are poor in resistance to distortion caused by this warp, and an inconvenience such that a crack is produced can occur. The larger the number of layers and the layer thickness of the dielectric films, the more likely a crack will occur, so that it is preferable that the thickness does not exceed approximately 1 μm. Therefore, the dielectric films can realize both mass producibility and a high reflectance when these are provided on the order of ten layers or less in terms of the number of layers and at 1 μm or less in terms of the thickness.

Hereinafter, we will describe some different embodiments of a scintillator panel according to the present invention. FIG. **15** is a sectional view showing a configuration of a second embodiment of a scintillator panel according to the present invention, and FIG. **16** is an enlarged view of a part XVI thereof. The configuration of this scintillator panel **100a** is basically the same as that of the scintillator panel **100** of the first embodiment shown in FIG. **2** and FIG. **3**, and differs only in the point that an amorphous carbon substrate **10a** is used in a support **1a** in place of the aluminum substrate **10**. In the amorphous carbon substrate **10a** as well, for the same reason as that of the first embodiment, it is preferable to provide the thickness as 0.3 mm or more and 1.0 mm or less. In this embodiment as well, an optical image with a high intensity can be obtained as in the first embodiment. Since the amorphous carbon substrate has a higher radiation transmittance than that of the aluminum substrate, a more satisfactory optical image can be obtained.

FIG. **17** is a sectional view showing a configuration of a third embodiment of a scintillator panel according to the present invention. This scintillator panel **101** differs only in the point that a ten layered dielectric film mirror **2b** is used in place of the dielectric film mirror **2** of the first embodiment. As a lamination order of the dielectric film mirror **2b**, as in the dielectric film mirror **2** of the first embodiment, the SiO<sub>2</sub> film **21a** with a low refractive index is provided as a first layer on



## 11

the metal reflection film **11** and the TiO<sub>2</sub> film **22a** with a high refractive index is thereon provided as a second layer, and then the lamination of the SiO<sub>2</sub> film and TiO<sub>2</sub> film is repeated four times. As in the first embodiment, the thickness of the SiO<sub>2</sub> films **21a** to **21e** is 95 nm, and the thickness of the TiO<sub>2</sub> films **22a** to **22e** is 60 nm. According to the present embodiment, since a reflection layer with a high reflectance of 99.85% can be realized as shown in FIG. **12** and Table 1, an optical image with a higher intensity can be obtained. Meanwhile, even when more than ten dielectric layers are laminated, the improvement in reflectance is slight, and the difficulty in lamination is increased, the yield of products and the like is also lowered, and the manufacturing cost is also increased, and thus a lamination of more than ten layers is not preferable.

FIG. **18** is a sectional view showing a configuration of a fourth embodiment of a scintillator panel according to the present invention. This scintillator panel **102** differs only in the point that the reflection protective film **30**, which has been provided in the first embodiment, is excluded from a support **1c**. Although it is more preferable to provide the reflection protective film **30** as in the first embodiment in consideration of the point of protecting the metal reflection film **11** from deterioration due to the scintillator constituent and the point that the reflectance is slightly improved, the reflection protective film **30** is not an essential component of the present invention. In the present embodiment, two dielectric layers compose the dielectric film mirror **2**, and since these two dielectric layers function as a protective film, deterioration of the metal reflection film **11** due to the scintillator constituent can be effectively inhibited even without the exclusive protective film **30**.

FIG. **19** is a sectional view showing a configuration of a fifth embodiment of a scintillator panel according to the present invention. This scintillator panel **103** is provided by further excluding the metal reflection film **11** of a support **1d** from the fourth embodiment. Smoothing the surface of the aluminum substrate **10** into a mirror surface makes it possible to provide the surface of the substrate **10** with the same function as the metal reflection film. Also, even in an incompletely mirrored state, the surface can be made to function as a reflection surface as long as a sufficient reflectance can be obtained. According to the present embodiment, a radiation image with a high intensity can be obtained by a simple configuration. Another metal substrate whose surface has light reflectivity may be used in place of the aluminum substrate. As metals other than aluminum, for example, gold, silver, and the like can be preferably used since the reflectance is high.

The present invention is not limited to the configurations of the above embodiments, and also includes combinations of the respective embodiments and replacements thereof, etc. For example, in the third and fourth embodiments, the substrate may be replaced by a substrate made of a metal other than aluminum, and further, this can be replaced by another radiation-transmissive substrate such as an amorphous carbon substrate, a silicon substrate, or a glass substrate.

In the above embodiments, SiO<sub>2</sub> has been used as the material of the first layer (low-refractive index layer) of the dielectric film layers, and as the material of the second layer (high-refractive index layer), TiO<sub>2</sub>, however, other materials may be used. As the material of the high-refractive index layer, a material containing at least one of the materials including TiO<sub>2</sub> as well as Nb<sub>2</sub>O<sub>5</sub>, Ta<sub>2</sub>O<sub>5</sub>, HfO<sub>2</sub>, and ZrO<sub>2</sub> can be used, for example.

In addition, stability of the metal reflection film may be improved by, for example, providing an inorganic or organic

## 12

film such as an oxide film between the substrate and metal reflection film. As a method for forming an oxide film, besides a method for forming an oxide film on the substrate by vapor deposition or the like, if the substrate is made of a metal, an oxide film may be formed by oxidizing the substrate surface.

Although the scintillator panel has herein been exemplified as a radiation image converting panel, a photostimulable phosphor such as CsBr doped with Eu may be used as a converting portion that converts a radiation image to an optical image to replace the scintillator. A radiation image is once converted by the photostimulable phosphor to a latent image, and a visible optical image can be read out by scanning this latent image with a laser light. The visible optical image thus read out is detected by various photodetectors such as, for example, a line sensor, an image sensor, and a photomultiplier.

What is claimed is:

**1.** A radiation image converting panel including a converting portion that converts a radiation image to an optical image on a support,

the support comprising:

a metal reflector; and

a dielectric film mirror including at least a first dielectric layer which is in contact with the metal reflector and formed thereon and a second dielectric layer which is formed on the first dielectric layer and has a higher refractive index than that of the first dielectric layer to light of an optical image outputted from the converting portion, wherein the converting portion is formed on the dielectric film mirror side.

**2.** A scintillator panel for which a scintillator composed of a plurality of needle crystals is formed on a support, the support comprising:

a metal reflector; and

a dielectric film mirror including at least a first dielectric layer which is in contact with the metal reflector and formed thereon and a second dielectric layer which is formed on the first dielectric layer and has a higher refractive index than that of the first dielectric layer to light emitted from the scintillator, wherein the scintillator is formed on the dielectric film mirror side.

**3.** The scintillator panel according to claim **2**, wherein the first

dielectric layer contains SiO<sub>2</sub>, and the second dielectric layer contains at least one material from TiO<sub>2</sub>, Nb<sub>2</sub>O<sub>5</sub>, Ta<sub>2</sub>O<sub>5</sub>, HfO<sub>2</sub>, and ZrO<sub>2</sub>.

**4.** The scintillator panel according to claim **3**, wherein the dielectric film mirror is formed by laminating three or more layers of the first dielectric layer and the second dielectric layer alternately.

**5.** The scintillator panel according to claim **4**, wherein a number of laminations of the dielectric film mirror is 10 layers or less.

**6.** The scintillator panel according to claim **4**, wherein a thickness of the dielectric film mirror as a whole is 1 μm or less.

**7.** The scintillator panel according to claim **2**, further comprising a transparent organic film which is formed, on the dielectric film mirror, at least between the dielectric film mirror and the scintillator, and has a lower refractive index than that of the second dielectric layer to light emitted by the scintillator.

**8.** The scintillator panel according to claim **2**, wherein the metal reflector is a thin metal film.

**9.** The scintillator panel according to claim **8**, further comprising a supporting substrate that supports the metal reflector.

**13**

10. The scintillator panel according to claim 2, wherein the metal reflector is a metal substrate.

11. The scintillator panel according to claim 8 or 10, wherein the metal reflector is formed of aluminum, silver, or gold.

12. A radiation image sensor comprising:  
a radiation image converting panel for which a converting portion that converts a radiation image to an optical image is formed, of a support including a metal reflector and a dielectric film mirror including at least a first dielectric layer which is in contact with the metal reflec-

5

10

**14**

tor and formed thereon and a second dielectric layer which is formed on the first dielectric layer and has a higher refractive index than that of the first dielectric layer to light of the optical image formed on the first dielectric film layer, on the dielectric film mirror side; and  
an image pickup device that converts an optical image outputted from the converting portion to an electrical signal.

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